Franco Postacchini

Lumbar Disc Herniation

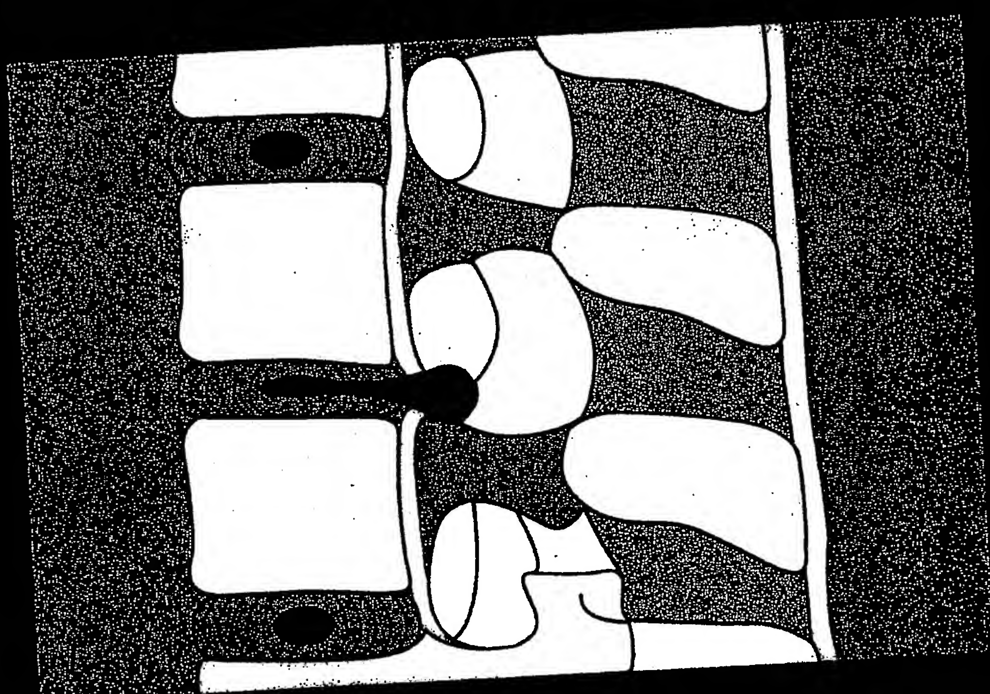

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Exhibit G

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Site of herniation

Midline herniation

Midline, or central, herniation occurs in the midportion of the disc (Fig. 5.18); that is, at the level of the central strand and the most medial portion of the lateral expansions of the posterior longitudinal ligament. Herniations in this site are rare at the high lumbar levels and, at any vertebral level, are usually represented by bulging of annulus fibrosus; this holds particularly for the high lumbar levels, where the central strand of the ligament is wider. Extruded herniations, furthermore, are mostly subligamentous, since in the middle portion of the disc the ligament is thicker and, therefore, more difficult for the extruded disc tissue to perforate.

The extruded fragment tends to remain in close proximity to the disc, due to the tenacious adhesion of the posterior longitudinal ligament to the posterior rim of the vertebral body. Less frequently the extruded tissue is directed towards the right or left side, between the longitudinal ligament and the annulus fibrosus, due to the poor adherence between the two structures over a large part of the rhomboidal portion of the ligament. Often, part of the extruded tissue displaces towards one side, whereas the residual portion remains in the subligamentous midline region.

The extruded fragment that succeeds in perforating the posterior longitudinal ligament is generally of large dimensions and, remaining in the midline, can impinge on the nerve roots of both sides in their intrathecal course. The fragment may migrate in various directions and, more easily than fragments extruded from other portions of the disc, can perforate the dural sac and become intrathecal.

Paramedian herniation

This herniation is that occurring in the centrolateral portion of the disc (Fig. 5.19). This portion corresponds to the zone occupied by the base of the lateral expansions of the posterior longitudinal ligament. The anatomic limits of this zone, however, are not well defined. Therefore, a herniation is often considered paramedian because it is a large herniation extending towards either the midline or the lateral portion of the disc. In the centrolateral zone of the disc, the posterior longitudinal ligament offers lower resistance than in the portion occupied by the median strap, but greater than in the posterolateral portion. For this reason, paramedian herniations are often contained, and extruded herniations are more often subligamentous than transligamentous or retroligamentous.

An extruded subligamentous fragment of disc tends to easily detach the posterior longitudinal ligament and slide behind the subjacent, or more rarely suprajacent, vertebra. If the ligament is completely detached in the caudal direction, or is perforated, the disc fragment tends to migrate medially to the emerging nerve root and subsequently in the axilla of the latter. In both cases, it can impinge on both the emerging root and the most lateral of the roots running within the thecal sac. When detachment occurs in the cranial direction, the fragment migrates towards the axilla of the nerve root emerging from the thecal sac at the level above.

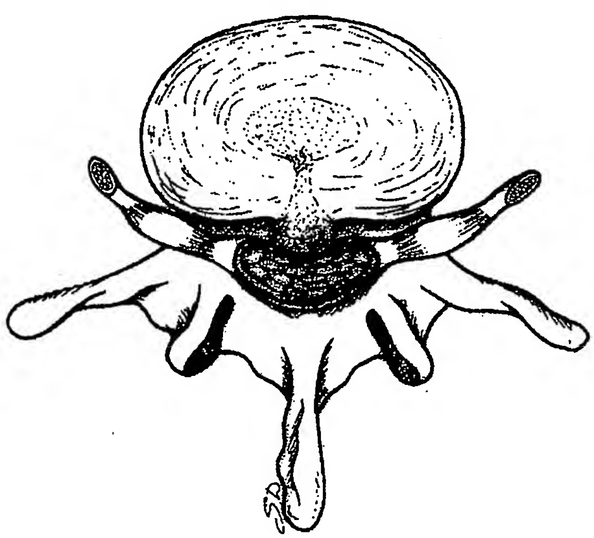

Fig. 5.18. *Midline disc herniation.*

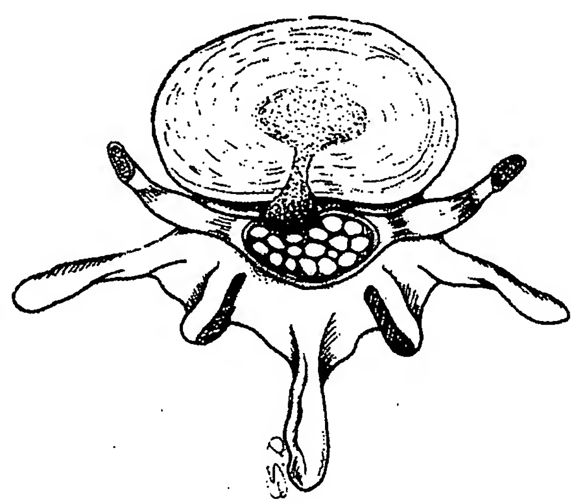

Fig. 5.19. *Paramedian disc herniation.*

Posterolateral herniation

This develops in the zone comprised between the base of the lateral expansion of the posterior longitudinal ligament and the entrance of the intervertebral foramen (Fig. 5.20). In this zone, facing the nerve-root canal, the disc is covered by the middle portion of the lateral expansions of the posterior longitudinal ligament. The lateral expansions are not only loosely adherent to the disc, but in the middle portion cover only part of the annulus fibrosus and this part progressively narrows from the first to the fifth lumbar disc. These anatomic characteristics may explain why posterolateral extruded herniations are more frequently transligamentous or retroligamentous compared with midline or paramedian herniations and why they are mostly located at the level of the two lower lumbar discs (58). These herniations, developing in the nerve-root canal, electively impinge on the emerging root and, thus, tend to produce more severe radicular signs and symptoms than midline or paramedian herniations.

Intraforaminal herniation

This herniation has been referred to with various terms: lateral (28, 30, 69), extreme lateral (1, 7, 60), far lateral (23, 29, 38), and foraminal (37). We prefer the term intraforaminal and distinguish this from the extraforaminal herniation; we use the term lateral as comprehensive of both types. Intraforaminal herniations are those located within the limits of the intervertebral foramen (Fig. 5.21). Often the herniation is partly intra- and partly extraforaminal. In this instance, the herniation takes the name of the site in which it is prevalently located; that is, a herniation located in the foramen for more than half of its axial dimensions is referred to as intraforaminal, whereas that located outside the foramen for more than half of its size is indicated as extraforaminal. Similarly, the herniation is termed posterolateral when less than half of its extension is situated in the foramen and the remaining portion, medially to the foramen.

Intraforaminal herniations can be contained, extruded or migrated. Within the foramen, the disc is not covered by the posterior longitudinal ligament and, thus, the extruded herniations cannot be classified as sub-, trans- or retroligamentous, like those of the posterior wall of the disc. Extruded herniations can be of two types: a) the herniated fragment escapes partially or completely from the disc, but remains in close proximity to the disc itself; b) the herniated tissue detaches the annulus fibrosus from the body of the vertebra above and locates just proximally to the caudal rim of the proximal vertebral body (Fig. 5.22). The latter condition is more frequent than the former. A contained herniation impinges on the nerve root emerging from the thecal sac at the intervertebral level above the herniated disc. The herniation, when it extends medially to the foramen, may also compress the root emerging from the sac at the level of the herniated disc.

Migrated herniations are characterized by the presence of a free fragment of disc tissue in the intervertebral foramen, at a distance from the disc. The fragment can originate both from the intraforaminal and the posterolateral zone, or even the paramedian portion, of the disc.

Intraforaminal migrated fragments locate ventrally and/or inferomedially to the nerve root running in the intervertebral foramen, i.e., behind the inferolateral

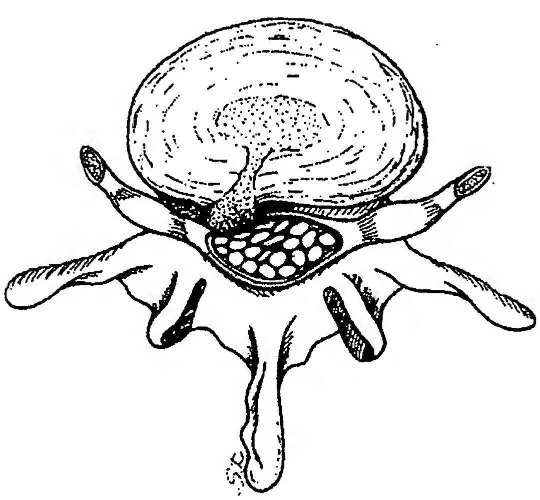

Fig. 5.20. *Posterolateral disc herniation.*

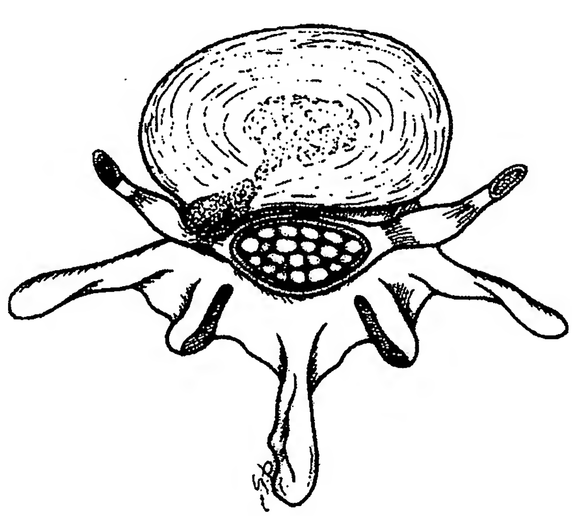

Fig. 5.21. *Intraforaminal disc herniation.*

At the end of the growing period, the spinal canal was reduced in its cross-sectional area, resulting in a slow compression of the cauda equina without epidural space violation. This model was found to cause, on average, a stenosis of 30% after 3 months and of 50% one year after surgery.

Biomechanics of radicular nerve compression

Various spinal conditions may cause compression of the radicular nerve or nerve roots. Since intrathecal nerve roots are embedded in the cerebrospinal fluid and occupy a limited space within the dural tube, they are less vulnerable to mechanical compression compared with radicular nerves. Therefore, a more severe compression is needed to damage the intrathecal nerve roots, particularly if the spinal canal is normal in size. Radicular nerves, instead, are more likely to be damaged by a mechanical compression, since they are less mobile than intrathecal nerve roots and, being outside the dural sac, are directly exposed to injuries.

Radicular nerve deformation differs in the presence of disc herniation, spinal stenosis or both.

Disc herniation

It has been shown that disc herniation causes mechanical compression at the contact zone with the radicular

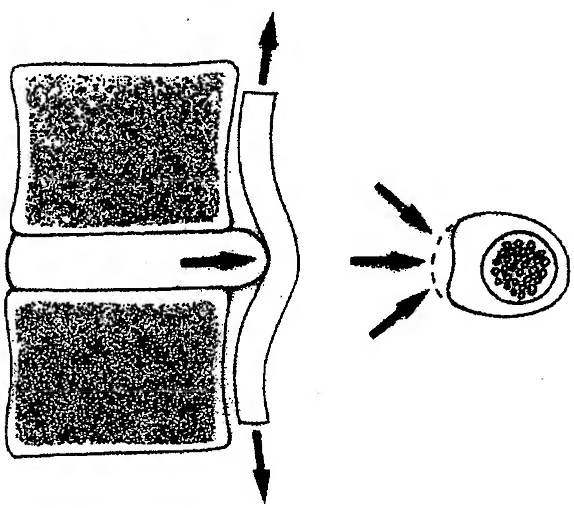

Fig. 6.3. *Compression of the radicular nerve by herniated disc. The herniation causes an asymmetric compression of the radicular nerve, whereby the nerve fibers are disclocated towards the opposite zone with respect to the applied force. Moreover, disc herniation produces tensile stresses in the zone of the radicular nerve above and below the contact area.*

nerve and intraneural tension in the areas above an below (120, 119) (Fig. 6.3). Since the mechanical com pression induced by disc herniation is asymmetri nerve fibers within the radicular nerve are displace towards the opposite zone with respect to the directio of the compressive force. The resulting nerve deforma tion is more marked at the edge of the compressed are where the nerve fibers, microvessels and connectiv tissue are more likely to be damaged (98, 123, 124). Th intraneural tension occurring in the areas adjacent to th contact zone may cause flattening and reduction of th transverse diameter of the nerve, thus increasing intra fascicular pressure and reducing the endoneural bloo supply (81). Nerve deformation greater than 15% wa found to completely block endoneural circulation (81)

A few factors may play a role in determining th severity of nerve injury caused by disc herniatio Reduced mobility of the radicular nerve may increas its susceptibility to mechanical compression. The mobi ity of the radicular nerve seems to be related to th dimensions of the spinal canal and to the presence c epidural ligaments anchoring the radicular nerve t the posterior longitudinal ligaments (Hoffmann's lig ments) and to the posterolateral border of the vertebr body at the level of the intervertebral foramen (139 These ligaments show a great variability in their mo phology among individuals, since they have bee found to be well developed in some and even absent i others (139). In the latter event, the radicular nerve ma be more mobile and less likely to be injured, wheret disc herniation might result in little or no pain. Th height of the herniated disc may be another facto influencing the severity of the radicular pain cause by disc herniation. In fact, it has been shown that di narrowing, by reducing the tension of the radicul nerve, decreases the pressure on the nerve itse induced by disc protrusion (140). The relief of radicul pain reported after intradiscal percutaneous trea ments, such as chemonucleolysis and percutaneo automated discectomy, may be related, at least in pa to this mechanism.

Stenosis

Spinal stenosis causes a circumferential deformation the radicular nerve, but the resulting increase in intr neural pressure was found to be less than that induce by disc herniation (36, 98, 126). While a posterior di protrusion of 5 mm was shown to cause a contact pre sure on the nerve of 400 mmHg (140), a circumferenti compression of the cauda equina causing a reduction the cross-sectional area by 67% was found to induce pressure of 100 mmHg on intrathecal nerve roc (131). Spinal stenosis causes nerve deformation due